Teaching Magnetism through the ISLE approach

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Videos of experiments by Gorazd Planinsic

August 2024 Magnetism workshop

Please rename yourself

First name

High School or college

Country

A few words about our approach to fields

A field is a model of interaction - it is a thing, an alterations of space properties due to the presence of some objects that participate in specific interactions.

These objects are called SOURCES and detectors or TEST OBJECTS

For electric field students learn two physical quantities that describe the field quantitatively - the vector quantity of $\vec{E}$ field and the scalar quantity of V field or electric potential.

Students should be able to

1. Describe the sources of magnetic fields. Explain how magnetic fields are created. “Read and write” with field line representations.
2. Explain how to use a compass to determine the direction and relative magnitude of the field at a particular location.
3. Determine the directions of B-field vectors when the magnetic field is created by a bar magnet, horseshoe magnet, and by a current-carrying wire, loop and a solenoid.
4. Apply the right-hand rule for the fields and the right-hand rule for forces to analyze situations involving magnetic fields when magnetic fields are created by current-carrying wires.
5. Compare and contrast electric fields and magnetic fields.
6. Determine the magnitude of a magnetic force exerted on a current-carrying wire or a moving charged particle in uniform magnetic field.
7. Apply knowledge of magnetic forces, electric forces and Newton’s laws to solve complex problems. Use force diagrams to analyze situations.
8. Explain how an electric motor works using knowledge of torques.
9. Describe how knowledge of magnetic fields applies to real-life and biological phenomena.
10. Describe and explain quantitatively the differences between dia-, para- and ferro- magnetic materials.
11. Design an experiment to determine the magnitude and direction of the field produced by a current-carrying wire, current-carrying solenoid and by an unmarked magnet.

Brief summary of student difficulties with magnetic fields

The biggest difficulty comes from the three-dimensional nature of magnetic phenomena –students need to use their hands to determine the direction of the field and of the magnetic force.

Students often forget that a magnetic field exerts a force only on moving charged particles but not on the stationary particles, and only if the particles are moving is a particular direction.

Students get confused when to apply each of the right-hand rules.

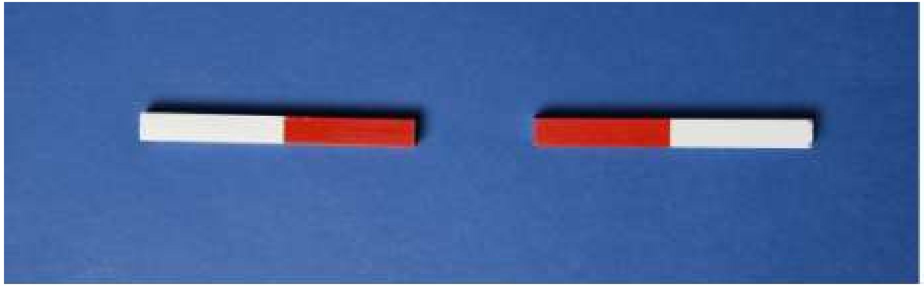
Some students think that a solenoid produces a magnetic field even when there is no current through the windings.

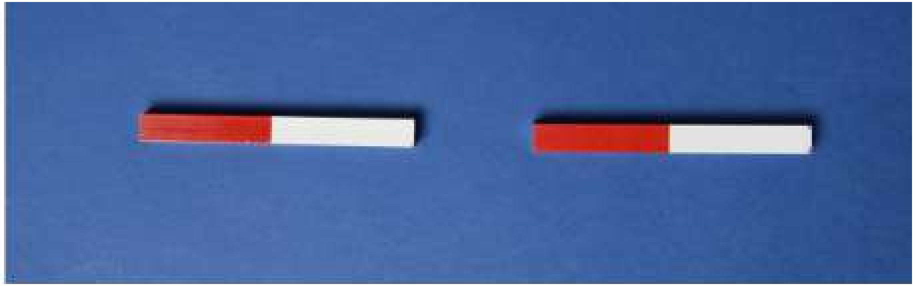
Students often think that the force exerted by one pole of a bar magnet on a diamagnetic or paramagnetic material will change the direction if the poles are swapped (the magnet is turned around).

Need to know

All together OALG 20.1.1 Observe and find a pattern

In the following video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-20-1-1 notice the markings on the ends of the bar magnets. (We used magnets that are marked with red (N) and white (S), but you may find other combinations such as brown (N) and white (S), red (N) and blue (S) and more.)





a. Describe your observations and record the patterns you found.

b. What other objects can interact at a distance in a similar way to magnets? What are the similarities and differences between

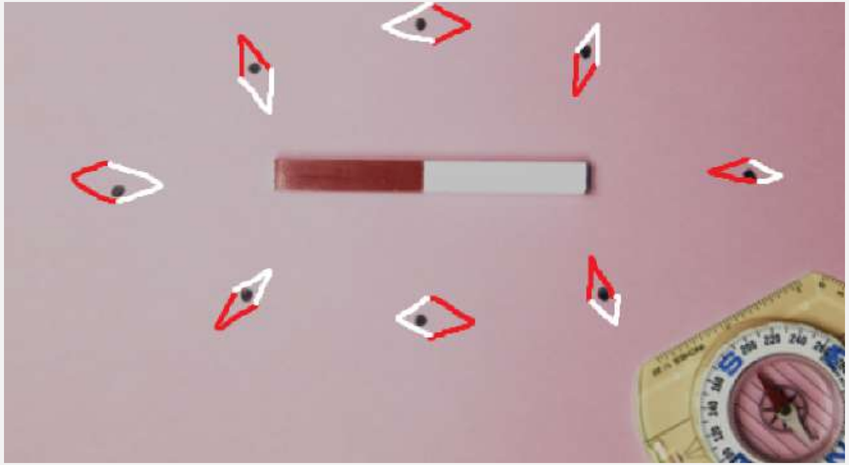
Team 1 OALG 20.1.2 Observe and find a pattern

In the following video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-20-1-2 the compass was placed on a table near the magnet and moved on the table around the magnet.

a. Draw pictures of the compass needle orientations for the locations marked in the figure below with points.

b. What are the patterns in the orientations of the compass needle?

c. What can you say about the space surrounding the magnet (based on the behavior of the compass needle)?



Team 2 OALG 20.1.2 Observe and find a pattern

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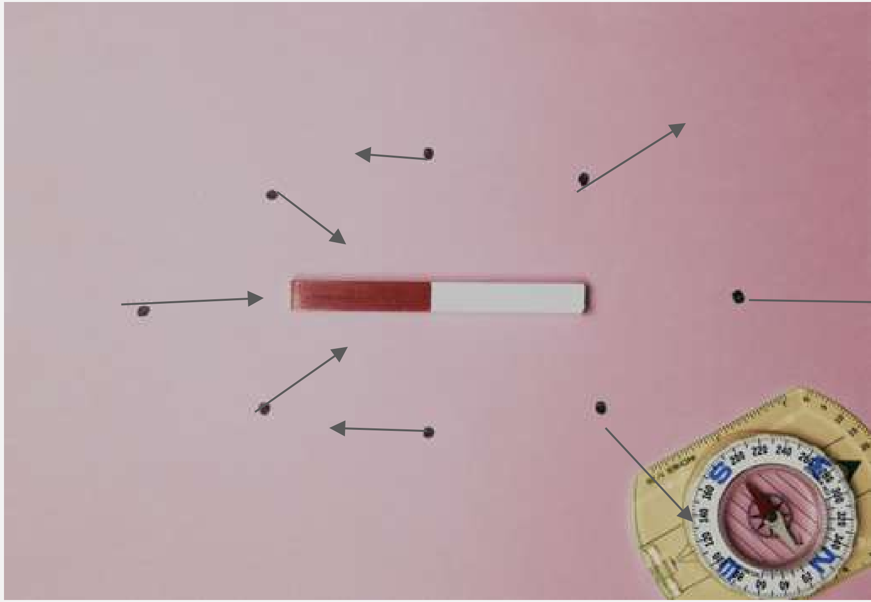


White arrow

Team 3 OALG 20.1.2 Observe and find a pattern

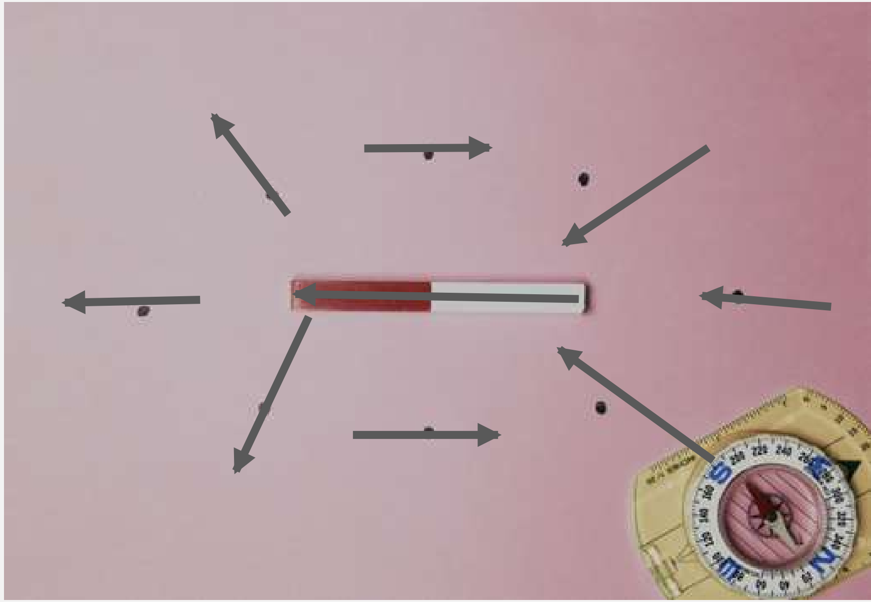
In the following video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-20-1-2 the compass was placed on a table near the magnet and moved on the table around the magnet.

a. Draw pictures of the compass needle orientations for the locations marked in the figure below with points.

b. What are the patterns in the orientations of the compass needle?

The opposite color was oriented towards the bar, for instance if it was closer to the white side, the red side of the compass was closer to the white side of the magnet.

c. What can you say about the space surrounding the magnet (based on the behavior of the compass needle)?

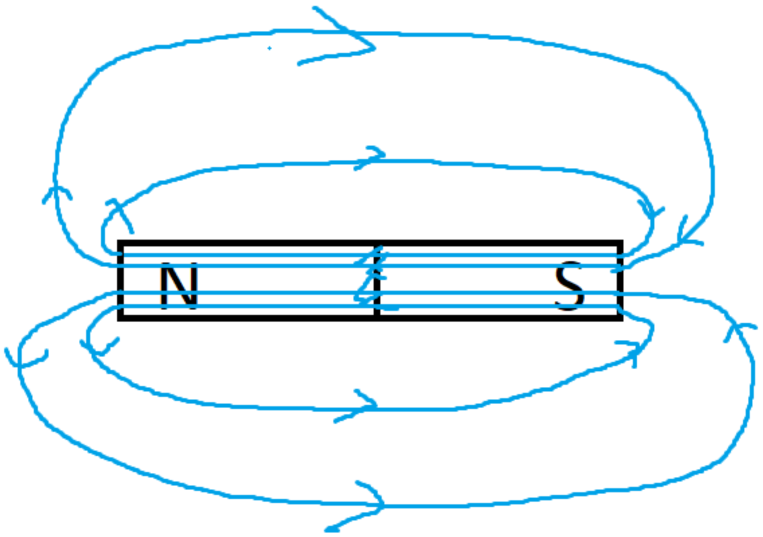


All together ALG 20.2.2 Observe and find a pattern

The *direction* of the field vector characterizing magnetic field is agreed to be the same as the direction in which the north pole of the compass points or the direction from the south to north pole inside the compass when it is at rest in the magnetic field.

a. Place a bar magnet on your whiteboard. Working together with your group members (each person can have their own compass) use your compasses to map the magnetic field around the bar magnet. Do this by drawing arrows that represent the direction of the field vector at many different points around the bar magnet. Then draw a line to which all vectors are tangent to create field lines. Share your results with another group.

b. How place your horseshoe magnet on your whiteboard and repeat the same process as before to create a map of the field lines around a horseshoe magnet. Again, share your findings with another group.


N
S

ALG 20.2.3 Observe, find a pattern and explain

The *direction* of the field vector characterizing magnetic field is agreed to be the same as the direction in which the north pole of the compass points or the direction from the south to north pole inside the compass when it is at rest in the magnetic field. In this experiment we will use the compass as an indicator of the *magnitude* of the field vector. Take a bar magnet and a compass but this time remove the cover from the compass so you can touch it with a tip of a pencil or other narrow nonmagnetic object. (Alternatively, you can use compass inside the cover and disturb its needle by waving a small magnet close to the compass). Place the magnet on a table and move the compass closer to the magnet along its axis. As you are moving the compass, stop at three distances as shown in the photo below and touch the compass, quickly disturbing the orientation of the needle. Then observe what happens to the needle.

https://www.youtube.com/watch?v=qqnquCL4bvo T = 2 pi srt l/g

Time for telling

What did we learn about magnets and compasses so far?

Why would a compass orient is a specific way at a location on Earth?

How do we define the direction of the B field vector?

Team 1 OALG 20.2.4 Observe and explain

In the following set of experiments https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-20-2-4 we investigated whether current carrying wires produce magnetic fields. Your task is to watch the video and answer the following questions (if you are having trouble, consult Observational Experiment Table 20.1 on page 619 in the textbook).

a. Why are both compasses oriented the same way before the current is turned on in the circuit? What is their orientation? Watch carefully to find N and S of the compasses.

Because only the Earth's magnetic field is present. They are oriented towards Earth's magnetic south pole. (assumption: red is north)

b. What can you say about the orientations of the compasses after the current is turned on in the first experiment? Do they turn in the same direction? Opposite?

Opposite.

c. How does the direction of each change in the second experiment?

The outcomes of the 1st and the 2nd experiment are mirrored.

d. What can you say about the magnetic field of the current-carrying wire based on these two experiments? Compare your answer to figure 20.9 on Page 620 in the textbook.

The magnetic field of the current-carrying wire is perpendicular on the wire. On top of it it points downwards in relation to the video,

e. Notice that the compass needles are not exactly perpendicular to the current carrying wire. Why could that be? (Hint: think of the magnetic field of Earth.)

The effects of the B fields of the wire and the Earth add up. (vector addition)

Team 2 OALG 20.2.4 Observe and explain

In the following set of experiments https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-20-2-4 we investigated whether current carrying wires produce magnetic fields. Your task is to watch the video and answer the following questions (if you are having trouble, consult Observational Experiment Table 20.1 on page 619 in the textbook).

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c. How does the direction of each change in the second experiment?

d. What can you say about the magnetic field of the current-carrying wire based on these two experiments? Compare your answer to figure 20.9 on Page 620 in the textbook.

e. Notice that the compass needles are not exactly perpendicular to the current carrying wire. Why could that be? (Hint: think of the magnetic field of Earth.)

a. The magnets point in the same direction as the Earth’s magnetic field. Both compasses point toward the Earth’s north pole (to the left)
b. After the current is turned up they point in opposite directions. The top points up and the bottom points down, perpendicular to the wire.
c. When the current changes direction the compasses are still in opposite directions but the top points down and the bottom points up, perpendicular to the wire.
d. ..
e. Adding earth magnetic field

Team 3 OALG 20.2.4 Observe and explain

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a. Why are both compasses oriented the same way before the current is turned on in the circuit? What is their orientation? Watch carefully to find N and S of the compasses.

They are oriented to Earth's magnetic field. The red is pointing towards north.

b. What can you say about the orientations of the compasses after the current is turned on in the first experiment? Do they turn in the same direction? Opposite?

They turn in opposite directions perpendicular to the direction of the current flow. The red arrows point in opposite directions, one points left, one points right (one compass is below the wire and one is above the wire.)

c. How does the direction of each change in the second experiment?

The current switches directions, and the red arrows of the compass switch their direction.

d. What can you say about the magnetic field of the current-carrying wire based on these two experiments? Compare your answer to figure 20.9 on Page 620 in the textbook.

The magnetic field has a direction (kind of like polarity).

e. Notice that the compass needles are not exactly perpendicular to the current carrying wire. Why could that be? (Hint: think of the magnetic field of Earth.)

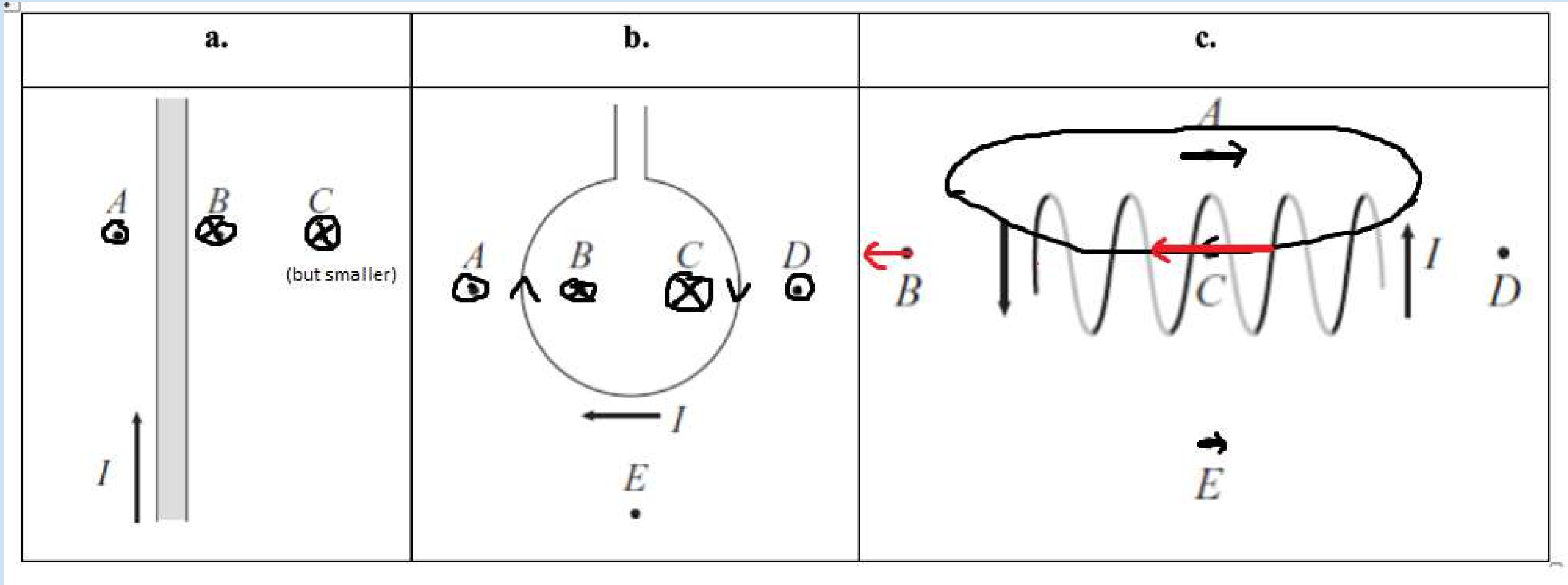
Team 3

Rule for the B field

Point the thumb of your right hand in the direction of the current (movement of the positive charge) and wrap the fingers around it. The direction of the fingers will be the direction of the B field line.

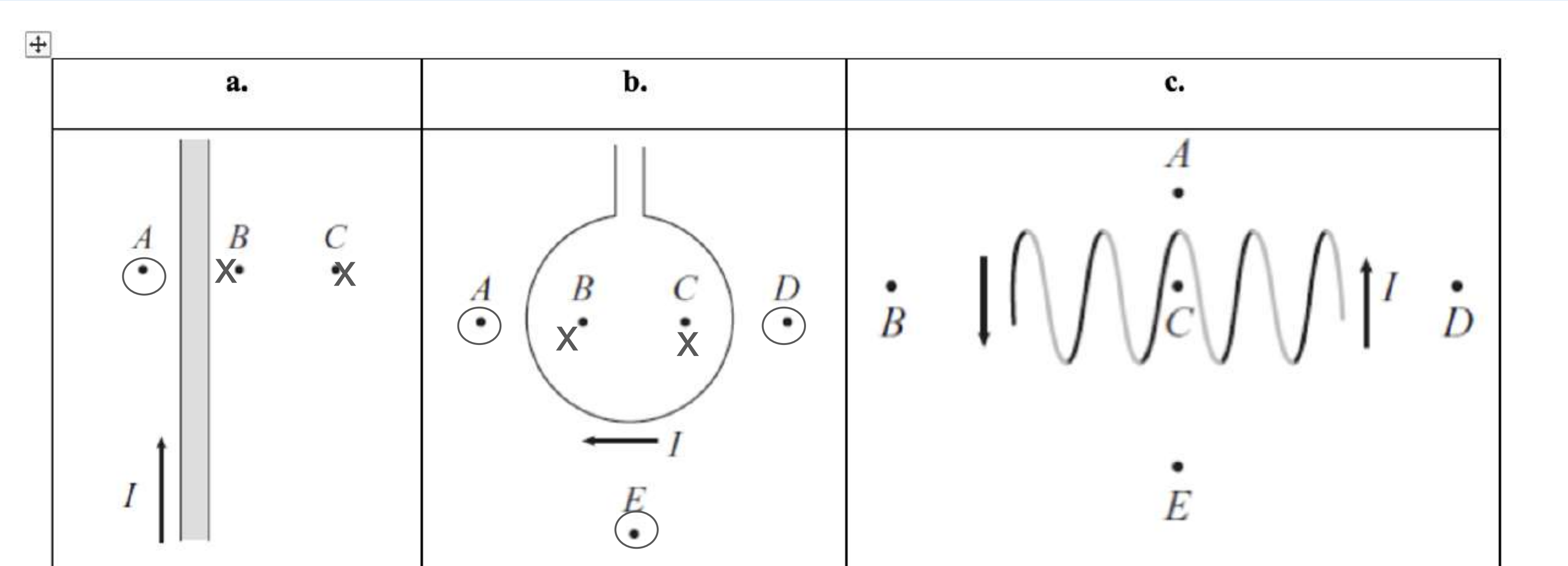
Team 1 OALG 20.2.6

There is current in each of the wires shown in the illustration below (the battery and the rest of the circuit are not shown). In cases **a**. and **b**., the current-carrying wires are in the plane of the paper. Case **c**. shows a solenoid (parts of wires that are further from you are black and those closer to you are gray). Determine the direction of the B field vector created by the current at the points indicated and draw it with an arrow, a dot (out of the page), or a cross (into the page).



Team 2 OALG 20.2.6

There is current in each of the wires shown in the illustration below (the battery and the rest of the circuit are not shown). In cases **a**. and **b**., the current-carrying wires are in the plane of the paper. Case **c**. shows a solenoid (parts of wires that are further from you are black and those closer to you are gray). Determine the direction of the B field vector created by the current at the points indicated and draw it with an arrow, a dot (out of the page), or a cross (into the page).



Team 3 OALG 20.2.6

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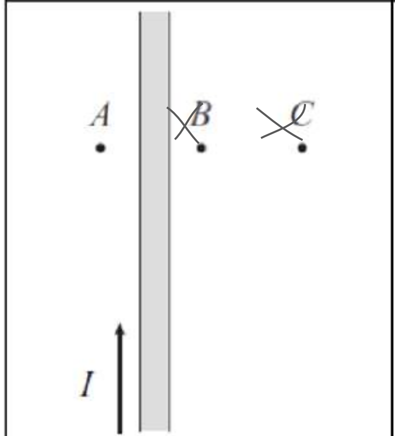
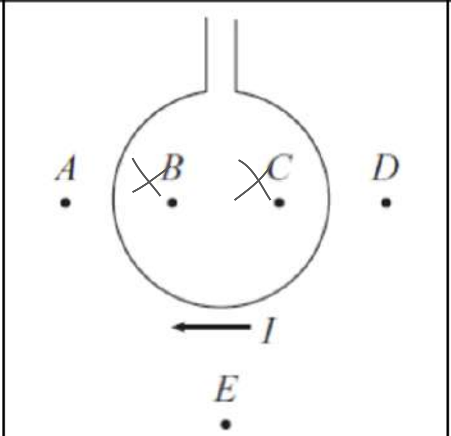
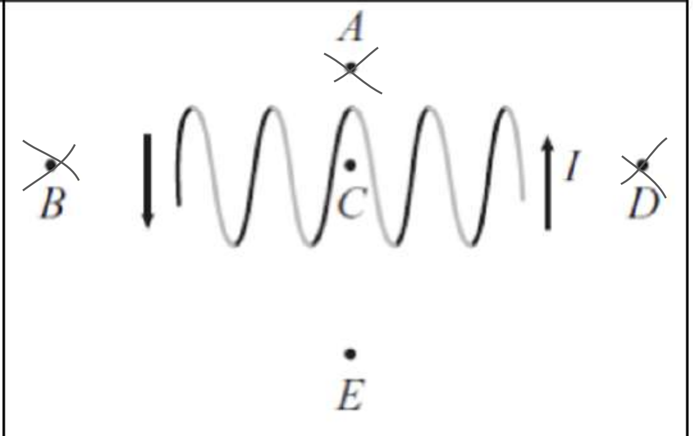
a.



b.



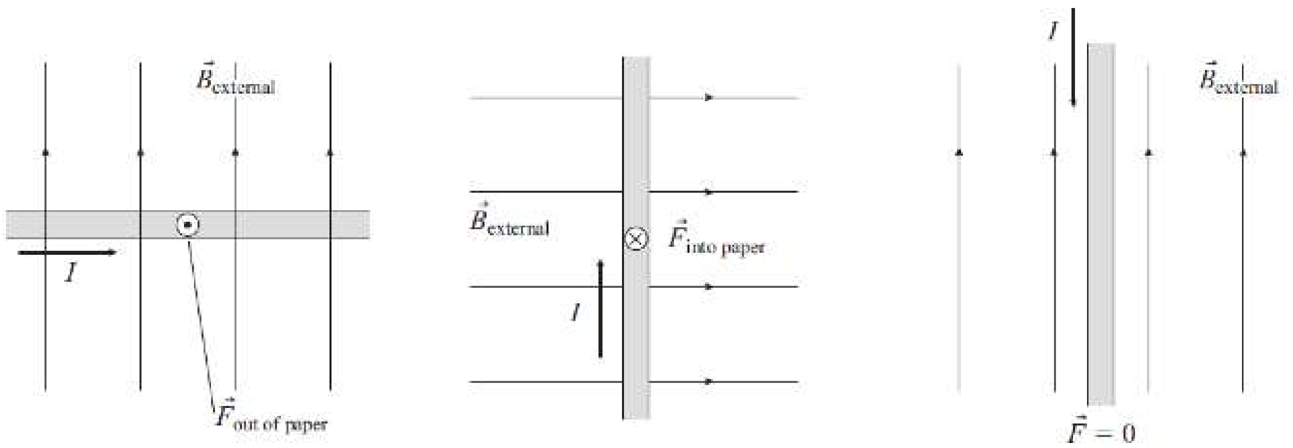
c.



Team 1 OALG 20.3.1 (Observe, explain, check your ideas)

A current-carrying wire is placed between the poles of an electromagnet. The direction of the $\vec{B}$ field lines produced by the magnet $\vec{B}_{\text{external}}$, is shown in the figure.

a. Invent a rule that relates the directions of the magnetic force $\vec{F}_{B\text{ on wire}}$, the directions of $\vec{B}_{\text{external}}$, and the directions of the current I in the wire.



b. Does your rule account for the outcomes of the experiments in the following video? https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-42 Explain.

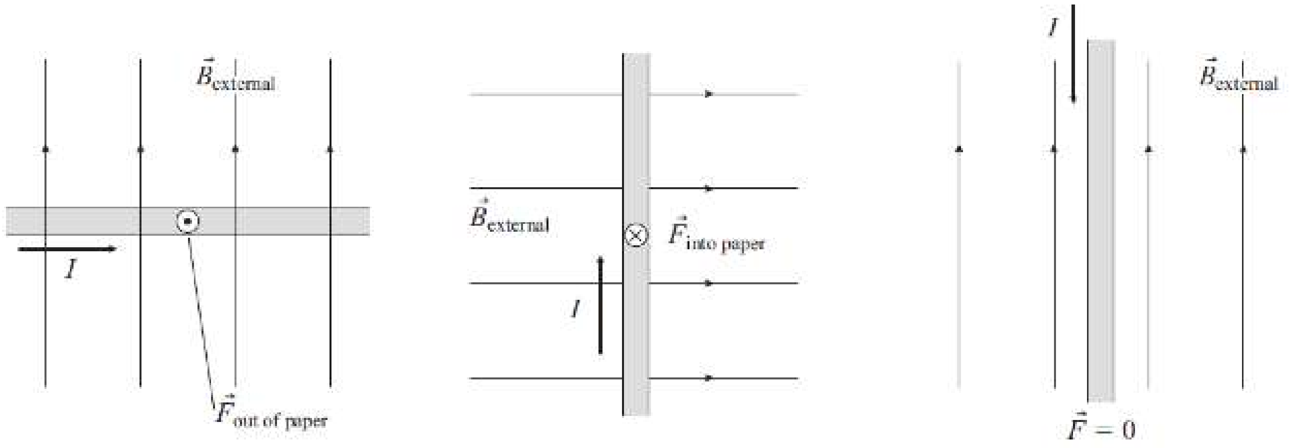
T1 observations

- In order for a force to appear on a current-carrying wire, the current direction should NOT be parallel to the external magnetic field.
- When the force on a CCW appears, it's perpendicular to both; the current and the ext. B-field.
- Since our fingers are flexible, maybe we can use them to point in the x, y, z, or rather I, B, F direction :) (thumb in the direction of the current, index finger in the direction of the ext. B-field, the middle finger points in the direction of the force).

Team 2 OALG 20.3.1 (Observe, explain, check your ideas)

A current-carrying wire is placed between the poles of an electromagnet. The direction of the $\vec{B}$ field lines produced by the magnet $\vec{B}_{\text{external}}$, is shown in the figure.

a. Invent a rule that relates the directions of the magnetic force $\vec{F}_{B \text{ on wire}}$, the directions of $\vec{B}_{\text{external}}$, and the directions of the current I in the wire.



b. Does your rule account for the outcomes of the experiments in the following video? https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-42 Explain.

If the current and the B field are perpendicular to each other the force is entering or exiting the plane (perpendicular to both of them)shows down or up

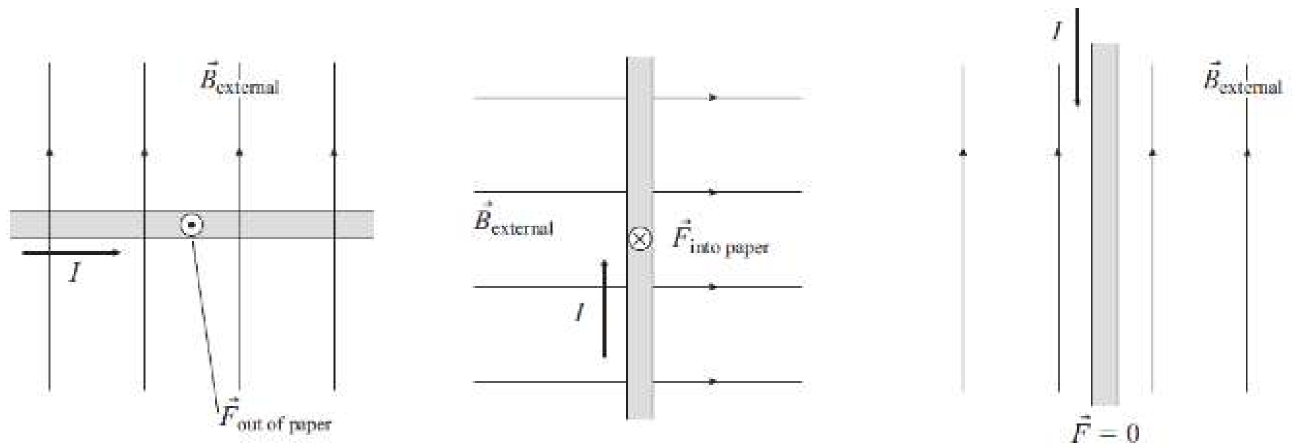
When the current and the B field are parallel then there is no force.

The angle

Team 3 OALG 20.3.1 (Observe, explain, check your ideas)

A current-carrying wire is placed between the poles of an electromagnet. The direction of the $\vec{B}$ field lines produced by the magnet $\vec{B}_{\text{external}}$, is shown in the figure.

a. Invent a rule that relates the directions of the magnetic force $\vec{F}_{B \text{ on wire}}$, the directions of $\vec{B}_{\text{external}}$, and the directions of the current I in the wire.



b. Does your rule account for the outcomes of the experiments in the following video? https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-42 Explain.

Team 3

1. Example: all three are mutually perpendicular

   I- thumb

   B- index finger

   F-middle finger

Current, I:

B field:

Force:

OALG 20.3.2 (Test)

Link to Question

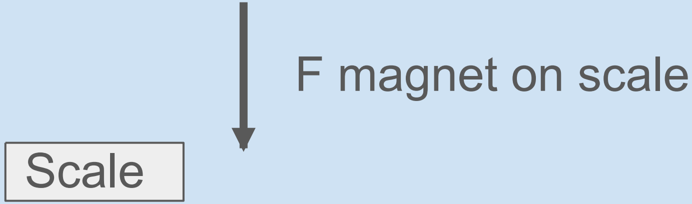
Team 1

Team 2

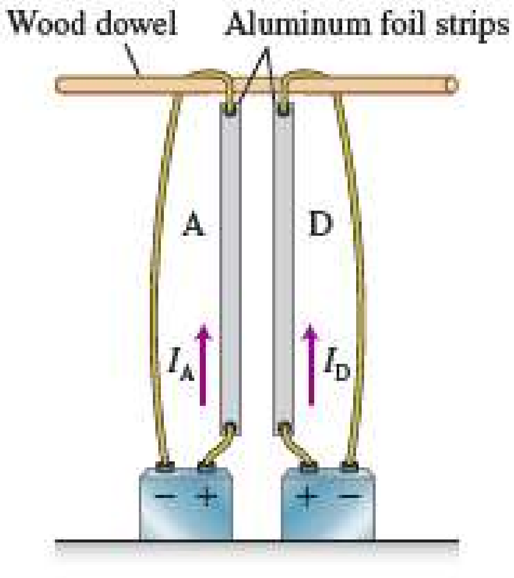
When current flows through the wire we can measure the change in force. If the force pushes the magnet down then the scale will have a higher reading because as the magnet pushes

Team 3

Using the right hand rule we predict the magnet will move the wire up and wire will push the magnet down. Therefore the magnet also push the scale down and predict the will show higher value.



Team 1 Test your ideas: Use the rule that you invented to predict the outcome of this experiment



Work together on a whiteboard

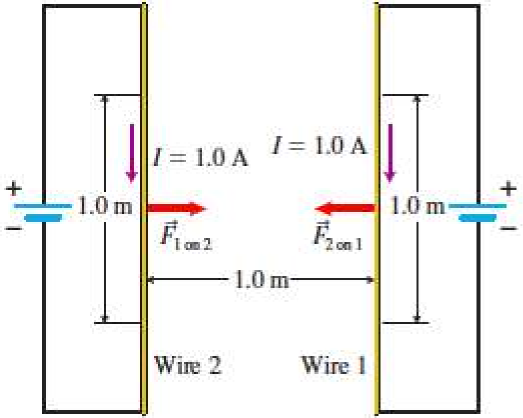
https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-egv2e-do-two-current-carrying-wires-interact-as-magnets-

Summary 20.3.1 + testing experiment

Summarize a rule that the whole class can use.

Time for telling

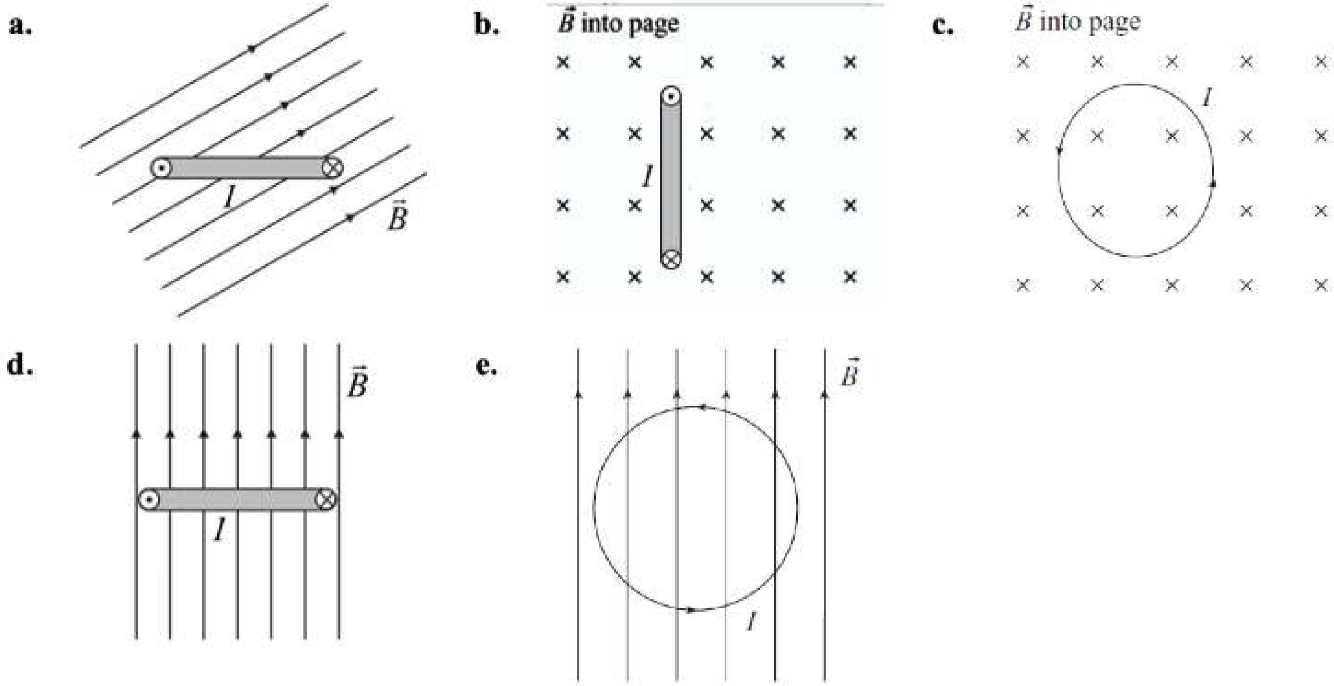
The currents are each defined as 1.0 A if the magnetic force that each meter of a long wire exerts on the other is 2.0×10^{-7} N.



$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = 2.0 \times 10^{-7} \text{ N}$$

OALG 20.3.5 Represent and reason

Decide whether the magnetic field exerts a nonzero torque on the current loop in each case pictured below. If so, and if the loop is initially at rest, which way would the magnetic torque cause the loop to start turning? For each case, draw in the forces on two opposite sides of the loop and show the direction of the net torque. (Current loops in parts **a**., **b**., and **d**. are perpendicular to the page.)



Team 1 OALG activity 20.3.3 parts a. and b. only

Link to activity

a) F α B, I, L, sin(angle between CCW and magnetic field vector)
   => F α B*I*L*sin(Θ)
b) They are the same.
c)

Team 2 OALG activity 20.3.3 parts a. and b. only

Link to activity

$F \propto B$; $F \propto I$; $F \propto L$; $F \propto \sin\Theta$

$F \propto BIL\sin\Theta$

Team 3 OALG activity 20.3.3 parts a. and b. only

[Link to activity]

$F \propto B$

$F \propto I$

$F \propto L$

$F \propto \sin \Theta$

$F \propto B \times I \times L \times \sin \Theta$

Get together whiteboard discussion: What did you find?

OD $B = F_{max}/IL$

C-ER B=

OD $E = F/q_{test}$

C-ER $E = kq_{source}/r^2$

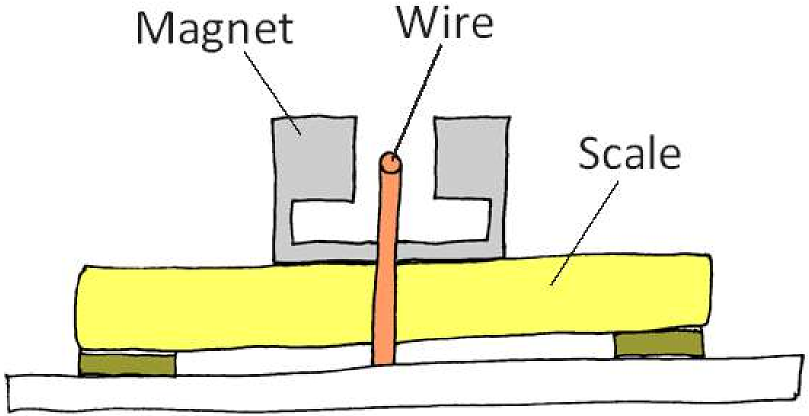
Team 1 part c

Team 2 part c

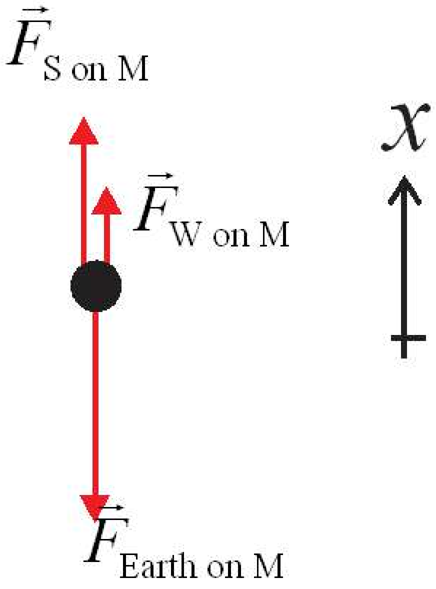
Team 3 part c

OALG 20.3.3.

Solution



Force diagram for the magnet



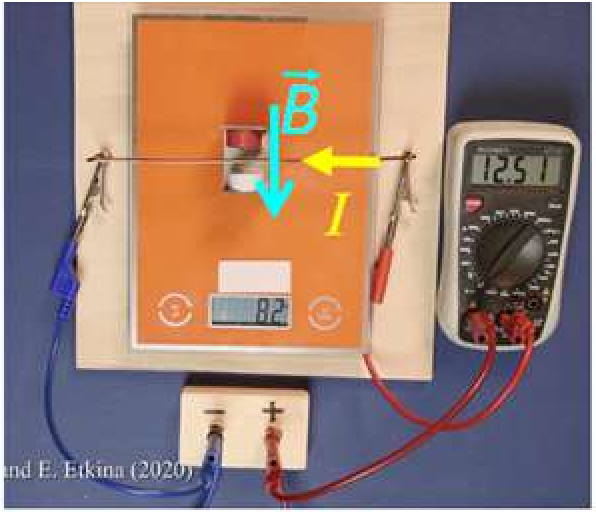
$$F_{\text{S on M}\,x} + F_{\text{W on M}\,x} + F_{\text{Earth on M}\,x} = 0$$

$$F_{\text{M on W}\,x} = -F_{\text{W on M}\,x} = F_{\text{S on M}\,x} + F_{\text{Earth on M}\,x}$$

$$F_{\text{M on W}\,x} = m_{\text{I}}g - m_0 g = \Delta m \cdot g$$

m_0 …scale reading when I=0

m_{I} …scale reading when I≠0



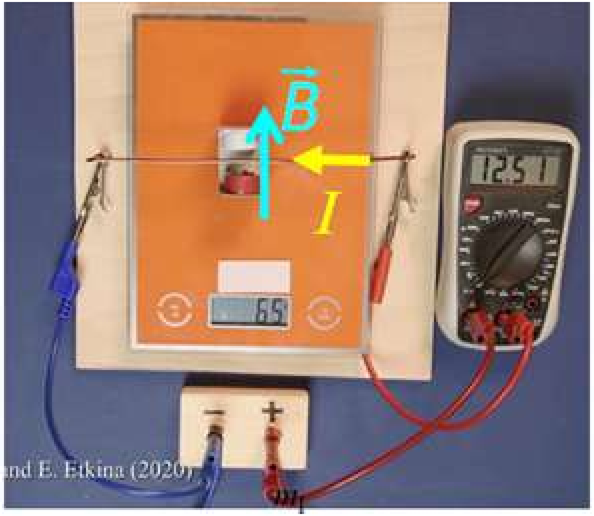
$I = 12.5\,\mathrm{A} \pm 0.05\mathrm{A}$

$m_{\mathrm{I}} = 82\ \mathrm{g} \pm 0.5\mathrm{g}$

$\Delta m = +9\ \mathrm{g} \pm 1\mathrm{g}$

$F_{\mathrm{M\ on\ W}\,x} = (88 \pm 10) \times 10^{-3}\ \mathrm{N}$

Direction: $\odot$



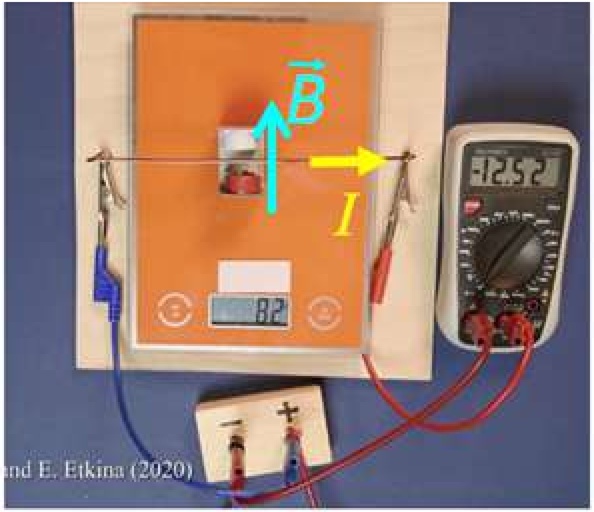
$I = 12.5\,\mathrm{A} \pm 0.05\mathrm{A}$

$m_{\mathrm{I}} = 65\ \mathrm{g} \pm 0.5\mathrm{g}$

$\Delta m = -\,8\ \mathrm{g} \pm 1\mathrm{g}$

$F_{\mathrm{M\ on\ W}\,x} = -\,(78 \pm 10) \times 10^{-3}\ \mathrm{N}$

$\otimes$



$I = 12.5\,\mathrm{A} \pm 0.05\mathrm{A}$

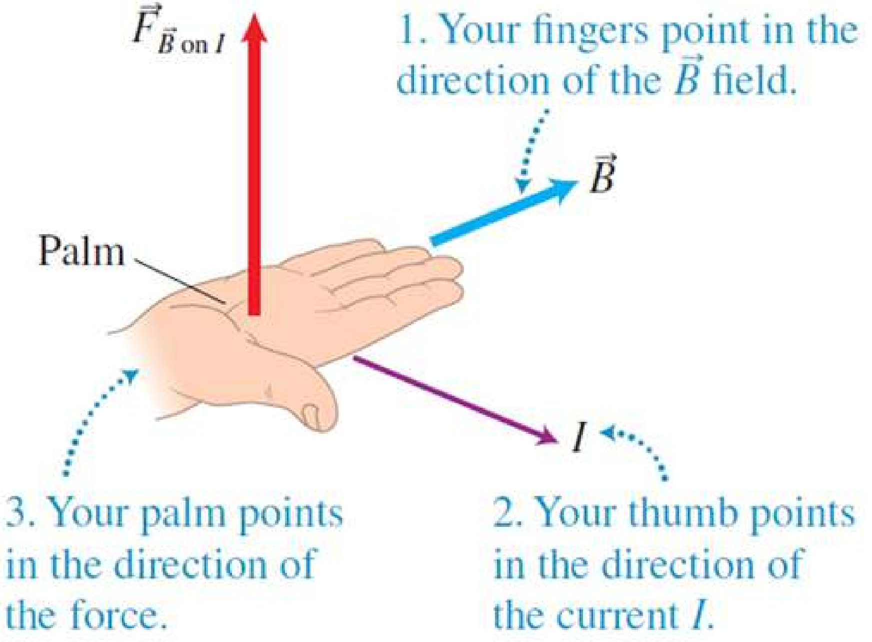
$m_{\mathrm{I}} = 82\ \mathrm{g} \pm 0.5\mathrm{g}$

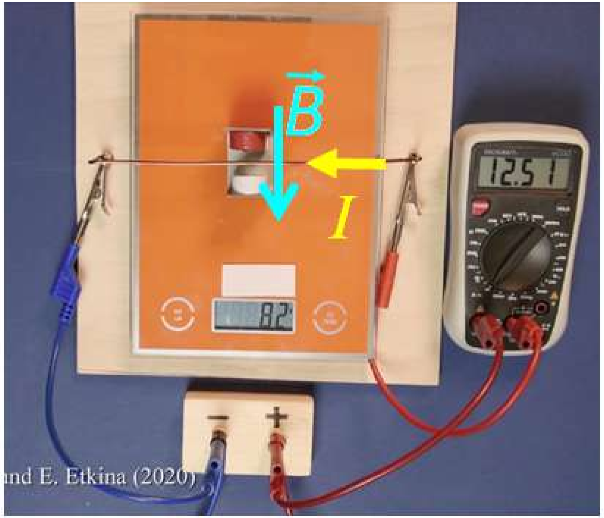
$\Delta m = +9\ \mathrm{g} \pm 1\mathrm{g}$

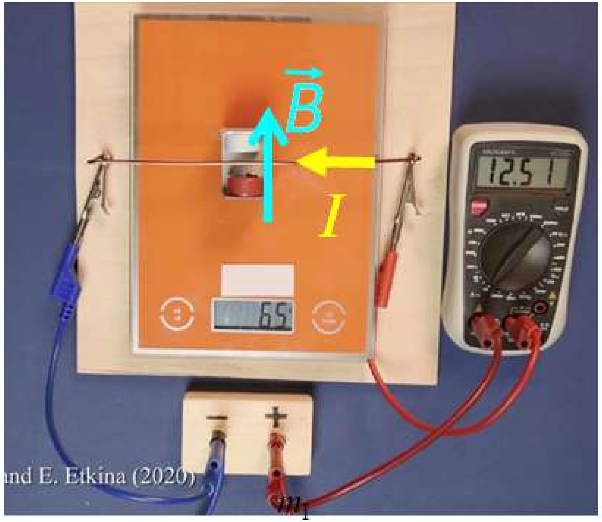
$F_{\mathrm{M\ on\ W}\,x} = (88 \pm 10) \times 10^{-3}\ \mathrm{N}$

$\odot$

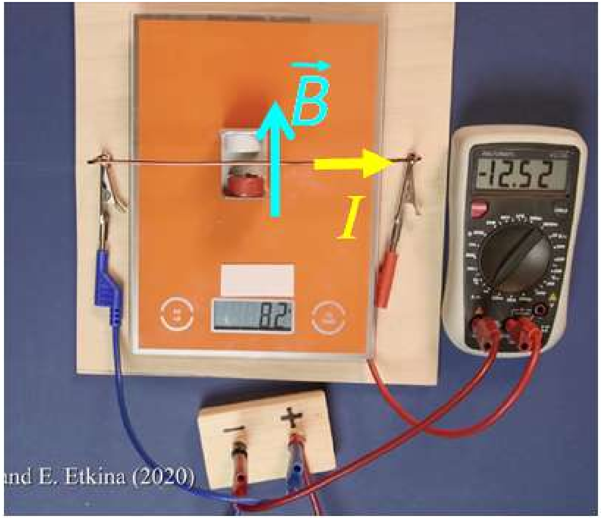
$$F_{\text{M on W}} = I \cdot L \cdot B$$







m_1



$I = 12.5\ \mathrm{A}$	$I = 12.5\ \mathrm{A}$	$I = 12.5\ \mathrm{A}$
$B = 0.33\ \mathrm{T}$	$B = 0.33\ \mathrm{T}$	$B = 0.33\ \mathrm{T}$
$L = 0.020\ \mathrm{m}$	$L = 0.020\ \mathrm{m}$	$L = 0.020\ \mathrm{m}$
$F_{\mathrm{M\ on\ W}\,x} = 83\times10^{-3}\ \mathrm{N}$	$F_{\mathrm{M\ on\ W}\,x} = -83\times10^{-3}\ \mathrm{N}$	$F_{\mathrm{M\ on\ W}\,x} = 83\times10^{-3}\ \mathrm{N}$

Direction: $\odot$ $\otimes$ $\odot$

Measured:

$F_{\mathrm{M\ on\ W}\,x} = (88 \pm 10) \times 10^{-3}\ \mathrm{N}$ $\quad$ $F_{\mathrm{M\ on\ W}\,x} = -\,(78 \pm 10) \times 10^{-3}\ \mathrm{N}$ $\quad$ $F_{\mathrm{M\ on\ W}\,x} = (88 \pm 10) \times 10^{-3}\ \mathrm{N}$

Direction: $\odot$ $\quad$ $\otimes$ $\quad$ $\odot$

Calculated using *F=ILB*:

$F_{\mathrm{M\ on\ W}\,x} = 83 \times 10^{-3}\ \mathrm{N}$ $\quad$ $F_{\mathrm{M\ on\ W}\,x} = -\,83 \times 10^{-3}\ \mathrm{N}$ $\quad$ $F_{\mathrm{M\ on\ W}\,x} = 83 \times 10^{-3}\ \mathrm{N}$

Direction: $\odot$ $\quad$ $\otimes$ $\quad$ $\odot$

Going back to the need to know

How do we explain aurorae?

Additional information: they happen about 2-3 days after solar storms (the Sun expels a huge amount of charged particles); they are seen most often close to the poles but when the storms on the sun are huge, they can be seen in everywhere on Earth.

Team 1 Explaining Aurorae

Team 2 Explaining Aurorae

Team 3 Explaining Aurorae

Team 4 Explaining Aurorae

What did you learn today? How did you learn it?

Coming up with the right hand rule based on the observations/videos. Then testing them to find the limits of the hypothesis. How to make rules by themselves.

It is ok to make mistakes and it is good to let students know that they should stand up for themselves and their observations.

Rules are what someone told you but now you can come up with the same rule using your own observations.

That the students are, after a finished chapter, ready to delve into harder chapters (explaining the need to know) on their own!

Distinguish operational definition and cause effect one.